HUMAN MARS ASCENT VEHICLE PERFORMANCE SENSITIVITIES

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Human Mars mission architecture studies have shown that the ascent vehicle mass drives performance requirements for the descent and in-space transportation elements. Understanding the sensitivity of Mars ascent vehicle (MAV) mass to various mission and vehicle design choices enables overall transportation system optimization. This paper presents the results of a variety of sensitivity trades affecting MAV performance including: landing site latitude, target orbit, initial thrust to weight ratio, staging options, specific impulse, propellant type and engine design.

Nomenclature

Isp	=	engine specific impulse
LCH_4	=	Liquid methane
LOX	=	Liquid Oxygen
MAV	=	Mars Ascent Vehicle
MDM	=	Mars Descent Module
MPS	=	Main Propulsion System
POST	=	Program to Optimize Space Trajectories
RCS	=	Reaction Control System
SEP	=	Solar Electric Propulsion
SLS	=	Space Launch System

Introduction

THE NASA Human Spaceflight Architectures Team is currently studying an Evolvable Mars Campaign[1] that aims to define an evolutionary path from current spaceflight infrastructure and capabilities to the ultimate goal of landing people on the surface of Mars and returning them to Earth. The Mars ascent vehicle (MAV) design has a significant effect on the Mars transportation architecture. Changes in MAV mass estimates ripple back through the architecture, affecting the entry and descent stage design of the lander as well as the performance for Earth launch and transportation to Mars.

The MAV's primary objective is to lift crew and cargo off the surface of Mars and dock with an orbiting Mars-Earth transportation vehicle. The MAV (without the oxygen propellant) is predeployed years in advance of a crew landing to allow adequate time for propellant generation. The MAV uses oxygen that is collected and liquefied on the Martian surface along with methane brought from Earth as propellant.

Crew cabin mass trades (seats vs no seats reduction in cabin mass)

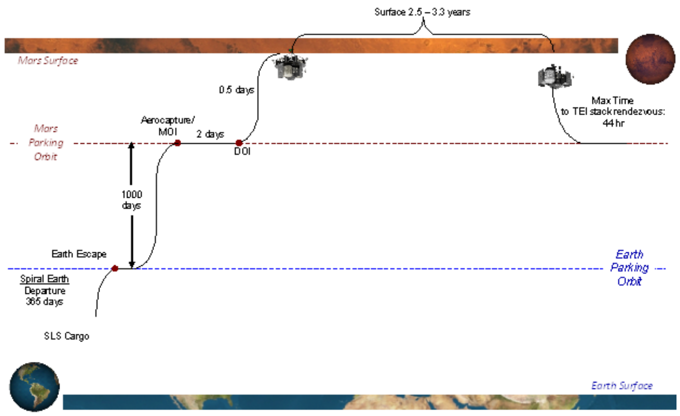


Figure 1. MAV Mission Overview.

Ascent Trajectory Design

The ascent performance of the MAV was modeled using Program to Optimize Space Trajectories (POST). The point of departure MAV trajectory originates from 30° north latitude and ends in the initial low Mars orbit of 100 km x 250 km with a 30° inclination. Three engines are used for the first stage, producing a liftoff acceleration of 0.78 Earth g's. Staging occurs at 225.8 seconds with a maximum acceleration of 1.52 Earth g's. The single second stage engine burns for 192.6 seconds to insertion into the low Mars orbit. Maximum acceleration during this burn is 1.10 Earth g's. These stage burn durations are optimized by POST based on the input propellant mass fractions of the stages.

The MAV then starts the sequence of burns using either the main engine of the 2nd stage or RCS, whichever is appropriate for the burn, to rendezvous with the Trans-Earth Habitat in a 1 sol orbit. The maximum acceleration during this phase of the mission is about 1.4 g's and occurs at the end of the "Coelliptic" maneuver (the only main engine burn after the 100 km x 250 km insertion).

Performance to target orbits of 500 km circular, 1 Sol and 5 Sol have been evaluated for a range of initial latitudes. Performance variation with specific impulse, initial thrust to weight ratio, staging and crew cabin mass have been evaluated. See figures 2-4.

Rendezvous options for 500km, 1 Sol, 5 Sol target orbits result in flight time and launch window constraints.

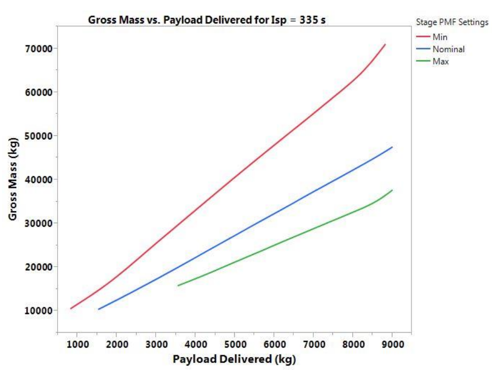


Figure 2. Storable Propulsion MAV, Sensitivity to variation in crew cabin mass, Isp = 335 seconds.

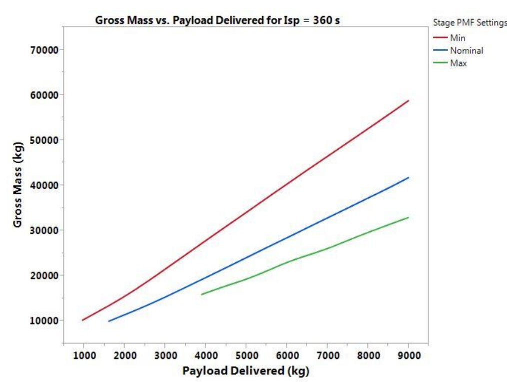


Figure 3. LOX/Methane MAV, Sensitivity to variation in crew cabin mass, Isp = 360 seconds.

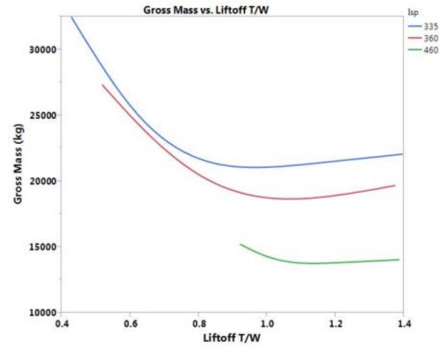
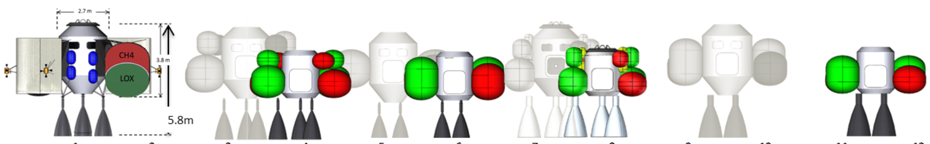


Figure 4. Sensitivity to lift off thrust to weight ratio.

Sensitivity to Propulsion System Design

Cryogenic propulsion systems allow for utilization of Martian resources for propellant production, but technology investments in ISRU and cryofluid management are required. Storable propulsion solutions exist that allow investments in ISRU and CFM to be delayed to later missions. Because all ascent propellant has to be launched from Earth, minimizing propellant mass is critical. Lower target orbits and smaller cabins may allow MAV solutions that are close to point of departure lander payload delivery requirements. See figure 5 for a comparison of propulsion options, including propellant, staging options, and crew cabin sizes.



	1	2	3	4	5	6	7	8	9	10	11	12
Target Orbit	5 Sol	1 Sol	500 km	500 km	500 km	500 km	500 km	500 km	500 km	500 km	500 km	500 km
MAV Cabin* (mt)	4.1	3.9	4	3.3	4	3.3	4	3.4	4	4	3.4	3.4
# of Stages	2	2	2	2	1	1	2	2	1	1	1	1
Propellant	LOX/CH4	LOX/CH4	LOX/CH4	LOX/CH4	LOX/CH4	LOX/CH4	MMH/NTO	MMH/NTO	MMH/NTO	MMH/NTO	MMH/NTO	MMH/NTO
Oxidizer (mt)	29.8	25	13.3	11.2	15.6	13.1	10.6	9 mt	12.7	18.4	10.9	15.9
Fuel (mt)	8.7	7.6	4.1	3.5	4.8	4	4.9	4.2 mt	5.9	8.5	5.1	7.3
MAV Total (mt)	48.8	42.4	27.9	23.5	29.4	24.7	22.6	19.5	25.9	37.7	22.2	32.4

Figure 5. Propulsion System Options.

While the point of departure MAV design relies on pump fed LOX/Methane propulsion, a pressure fed option has also been developed. Alternate MAV configurations have been studied. Impacts to aerodynamics and propellant residuals observed.

References

[1] Craig, Douglas A., Herrmann, Nicole B., and Troutman, Patrick A. "The Evolvable Mars Campaign – Study Status," IEEE Aerospace Conference, Big Sky, MT, March 7-14, 2015.

[2] Polsgrove, Tara P., Thomas, Herbert D., Sutherlin, Steve, Stephens, Walter, and Rucker, Michelle,. "Mars Ascent Vehicle Design for Human Exploration," AIAA SPACE 2015, Pasadena, CA, August 2015.